

Imaging the Interiors of Near-Earth Objects with Radio Reflection Tomography

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Scenarios for mitigation of asteroid/comet collisions include the use of explosives to deflect or destroy the projectile (Ahrens and Harris 1995). However, as demonstrated by Asphaug *et al.* (1998), the outcome of explosive energy transfer to an asteroid or comet (via a bomb or a hypervelocity impact) is extremely sensitive to the pre-existing configuration of fractures and voids. A porous asteroid (or one with deep regolith) significantly damps shock wave propagation, sheltering distant regions from impact effects while enhancing energy deposition at the impact point. Parts of multi-component asteroids are similarly preserved, because shock waves cannot bridge inter-lobe discontinuities. Thus our ability to predict the effect of detonating a nuclear device at an asteroid or comet will rest on what we know about the object's interior.

Information about the interiors of near-Earth objects is extremely limited. Results from NEAR-Shoemaker's year-long rendezvous of Eros (Prockter *et al.* 2002, Veverka *et al.* 2000) suggest that it is somewhat consolidated, with a pervasive internal fabric that runs nearly its entire length and affects some mechanical responses such as fracture orientation. However, Eros' detailed internal arrangement of solid and porous domains is unknown, and in any case, Eros is not hazardous and is orders of magnitude more massive than any potentially hazardous asteroid. For much smaller asteroids whose shapes have been reconstructed from ground-based radar imaging (e.g., Hudson and Ostro 1995, Hudson *et al.* 2000) and for radar-detected comet nuclei, (Harmon *et al.* 1999), some interesting but non-unique constraints on density distribution have resulted.

We would like to suggest that Radio Reflection Tomographic Imaging (RRTI) is an optimal technique for direct investigation of the interior of a small body by a spacecraft in orbit around it. The RRTI instrument's operation frequency is low enough so that its radio signals are able to probe the target body's interior. The data obtained by RRTI is three-dimensional since it consists of wideband echoes collected on a surface around the object. This three-dimensional data set can be operated on to obtain the three-dimensional spatial spectrum (also known as the range-Doppler distribution) of the object. The inversion of the RRTI data can yield the three-dimensional distribution of complex dielectric constant, which in turn can reveal the presence of void spaces, cracks, and variations in bulk density.

The mathematical basis of the technique is similar to that of ultrasonic reflection tomography (Kak and Slaney 1988) and seismic imaging (Mora 1987). Design of a spaceborn RRTI instrument for a small-body rendezvous can be based on the heritage from other planetary radar sounders like MARSIS (Picardi *et al.* 2001) and radar sounding experiments used to study glaciers (Gudmandsen, 1971) or contemplated for searching for a Europa ocean (Johnson *et al.* 2001). However, unlike these planetary radar sounding instruments, RRTI of NEOs would exploit the spacecraft's access to all sides of the body. Global views of the object make it possible to solve for the three-dimensional dielectric constant variations within the object down to the size of the shortest observing wavelength.

RRTI is distinctly different from radio transmission tomography techniques (e.g. the CONSERT experiment on Rosetta; Kofman *et al.* 1998) whose purpose is not imaging but rather to study material properties of radio-transparent comets. RRTI is an imaging technique that uses a co-located transmitter and receiver, and therefore does not require that the illuminating signal pass entirely through the target.

Therefore, an RRTI system can be used to image the interiors of both comets and asteroids throughout the volume penetrated by the radar echoes.

The volumetric dielectric properties of the asteroid or comet can be reconstructed using least-squares inversion (e.g., a conjugate gradient search; Safaeinili and Roberts 1995, Lin and Chew 1996) driven by the observed difference between model-predicted radio echoes and the measured radio signals. A computationally less intensive and reasonably accurate inversion is possible with the Born approximation, which ignores multiple reflection within the target (a good first approximation for targets with high attenuation) and linearizes the dependence of the scattered field on dielectric variations.

See our poster for examples of simulated RRT images of the interiors of very simple models.

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